UNITED STATES MARINE CORPS

LESSON PLAN

ATMOSPHERIC FORCES

INTRODUCTION:

1. Gain Attention. Have you ever wondered what makes the world turn?
Or what forces are out there that have such a huge affect on the
atmosphere?

2. Overview. During this period of instruction, the student shall be
introduced to the different forces in the Earth's atmosphere that
affect global wind and pressure patterns.

3. Introduce Learning Objectives.

    a. Terminal Learning Objective. Without the aid of references,
    but in accordance with this period of instruction, demonstrate how
    each atmospheric force affects the movement of an air parcel within
    the atmosphere.

    b. Enabling Learning Objective(s). Without the aid of
        references, complete the following tasks:

        (1)   Define Pressure Gradient Force and how it acts to
        initiate the winds.

        (2)   Explain what causes the Coriolis Force and its
        relationship between magnitude and latitude.

        (3)   Define Centrifugal Force and the type(s) of pressure
        systems that affect it.

        (4)   State the affect that friction has on parcels of air at
        the surface and aloft.

4. Method/Media. This period of instruction will be taught using the
lecture method with aid of QMMCBT-001 "Introduction to the Dynamics of
the Earth's Atmosphere".

5. Evaluation.   The student shall be evaluated by physically
depicting how each atmospheric force affects the path of an air parcel.

TRANSITION. Air parcels follow the laws of physics as they move
throughout the atmosphere and they may be real or apparent forces. The
force that acts to initiate the wind is called the Pressure Gradient
Force.

BODY:

1. The Pressure Gradient Force. To get an object to accelerate, or
change its velocity, it requires an unbalanced force in one direction.

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When air is subject to a greater force on one side than on another, the imbalance produces a force that is directed from higher to lower pressure. These pressure differences then cause the wind to blow, with greater pressure differences resulting in greater wind speeds.   This force is called the *Pressure Gradient Force* (PGF).

    a.   The Pressure Gradient Force can be computed by determining the amount of pressure change over a given distance. It is represented mathematically as: PGF = $\Delta P / \Delta n$, where "ΔP" is the amount of pressure change, and "Δn" is the distance.

    b.   The pressure gradient is a vector with the direction always being perpendicular to the isobars, along the "n" axis (the vector always pointing to the +n side). The magnitude can be computed using the equation above and is directly proportional to the amount of the pressure change over a distance. Simply stated, the greater the change in pressure, the stronger the PGF.
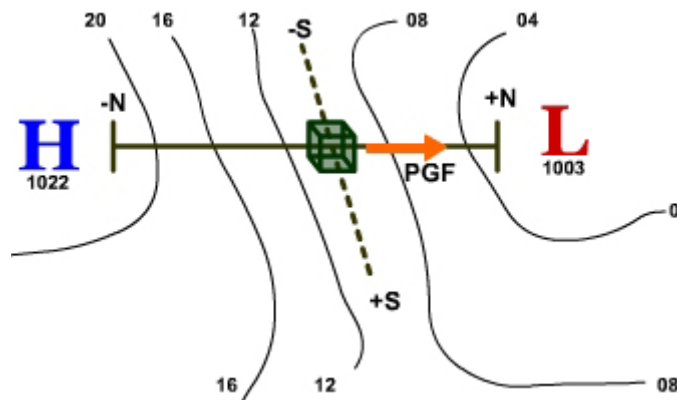

Figure 1 – PGF is a vector always pointing along the +n axis towards lower pressure.

    c.   Changes in pressure result from a change in the quantity of mass over a location. There may be a net removal or addition of mass, or a change in density over a region due to the unequal heating of the land-sea surface.

    d.   The term Pressure Gradient Force is commonly used to describe the pressure changes and wind flow at the surface. Aloft, the same principle is taking place, however since pressure changes are depicted by contours that represent height changes, it is referred to as the *Height or Contour Gradient Force*. Mathematically stated HG (CG) = $\Delta z / \Delta n$, where "Δz" is the change in height, and "Δn" remains the given or measured distance.

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Tighter pressure gradients results in a stronger pressure gradient force which produces stronger wind speeds.
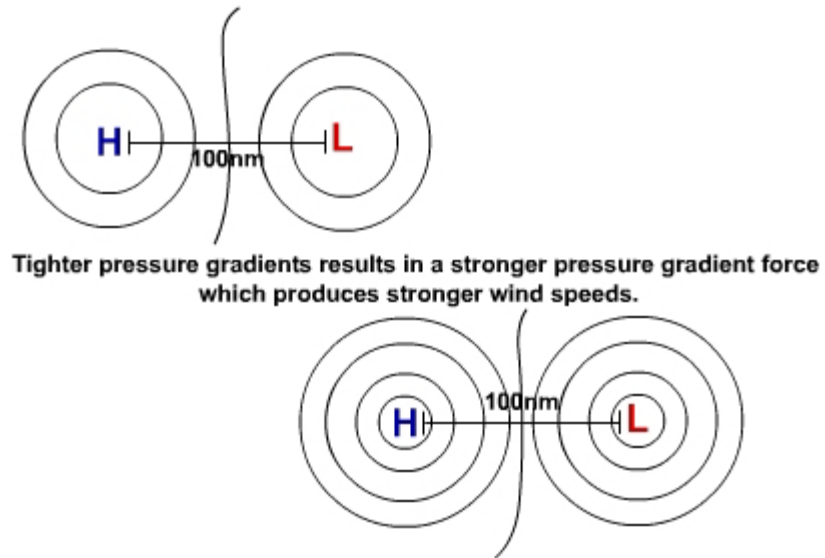
Figure 2 – The pressure gradient is directly proportional to the pressure gradient force.

TRANSITION. The PGF explains what sets the wind into motion, but once the wind begins to blow, the Earth's rotation changes its direction. This is known as the Coriolis effect.

2.   The Coriolis Force.

   a.   If the Earth did not rotate, winds would flow directly from higher to lower pressure. But the Earth rotates counter-clockwise, and therefore, affects the true direction of the air parcels.
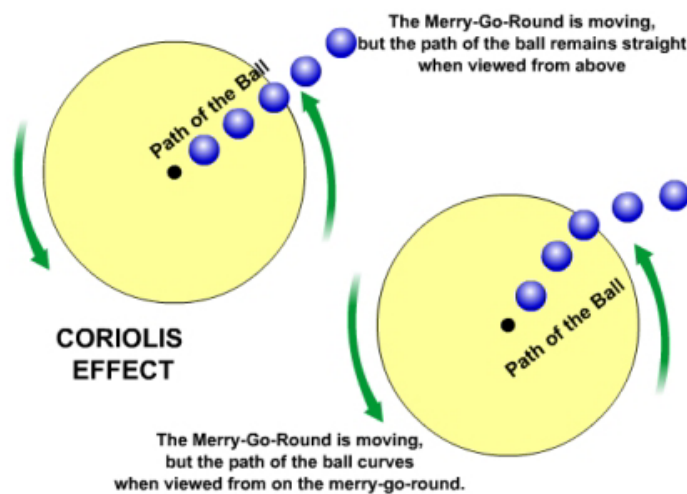

Figure 3 – The effect of a rotating platform on stationary and moving cameras.

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b.   In the Northern hemisphere, the rotation of Earth acts to deflect particles to the right of their path. This force is called the *Coriolis force* (CoF). It can be represented mathematically as CoF = fv, where "f" is Coriolis parameter and "v" is the linear velocity.

   (1)   The Coriolis parameter can also be stated mathematically as f = (2)Ωsin(θ), where "Ω" is the angular velocity of the Earth (always a constant), and "θ" is the latitude.

   (2)   The sine of 0 (0˚ at the Equator) is "0" and the sine of 90 (90˚ at the north and south poles) is "1". The coriolis parameter is directly proportional to latitude which, in turn, is directly proportional to the Coriolis Force. Therefore, the Coriolis force is negligent at the equator and increases as you go poleward.

c.   The effect of the Coriolis force is an apparent deflection of the path of an object that moves upon the rotating Earth. The object does not actually deviate from its path, but it appears to do so because of the motion of the coordinate system.

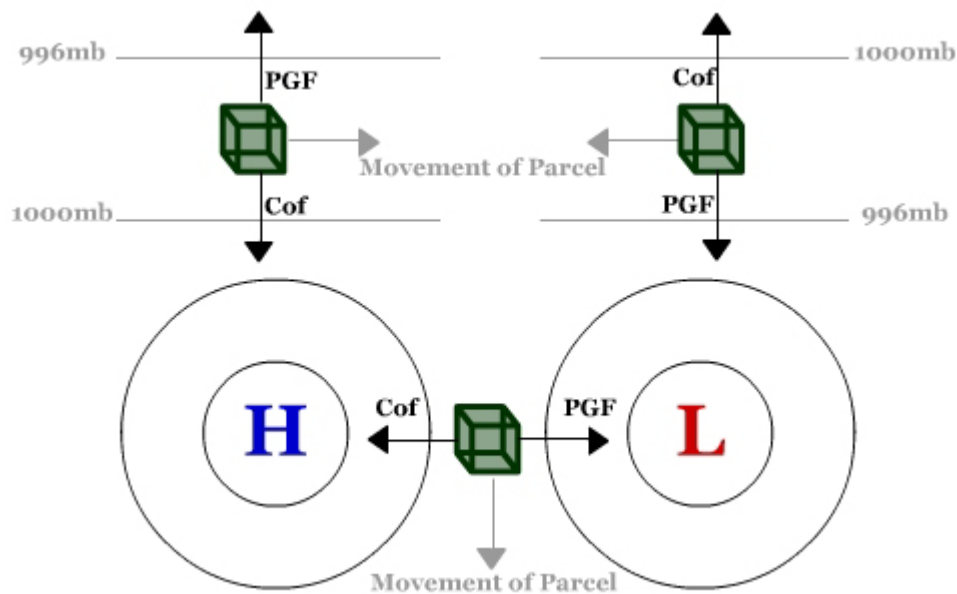d.   The Coriolis Force acts 90 degrees to the right of parcel movement.

Figure 4 – The Cof is always directed ninety degrees to the right of the flow.

TRANSITION. We have just discussed the force that acts to initiate the winds, as well as, the apparent force that is caused by the rotation of the Earth. The next force is one we have all experienced. That is the force that acts to push you outward as you make a sharp turn around a corner while driving a vehicle. This force is known as the Centrifugal Force.

3. Centrifugal Force. *Centrifugal force* (Cef) is the experience of the inertia (*inertia is defined as the tendency of a body to maintain*

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its state of uniform motion unless acted on by an external force) of an object moving in circular motion, causing it to move away from the center. It is a type of inertial force. An inertial force is a fictitious force used for convenience in visualizing the effects of forces on bodies in motion. For an accelerating body, the inertial force is considered as a body force whose resultant acts at the object's center of gravity in a direction opposite the acceleration. The magnitude of the force is the mass of the object times the magnitude of the acceleration.

    a.   Centrifugal force is always directed outward from the axis of rotation perpendicular to the wind flow. It describes the balance of forces that are present with curved wind flow.
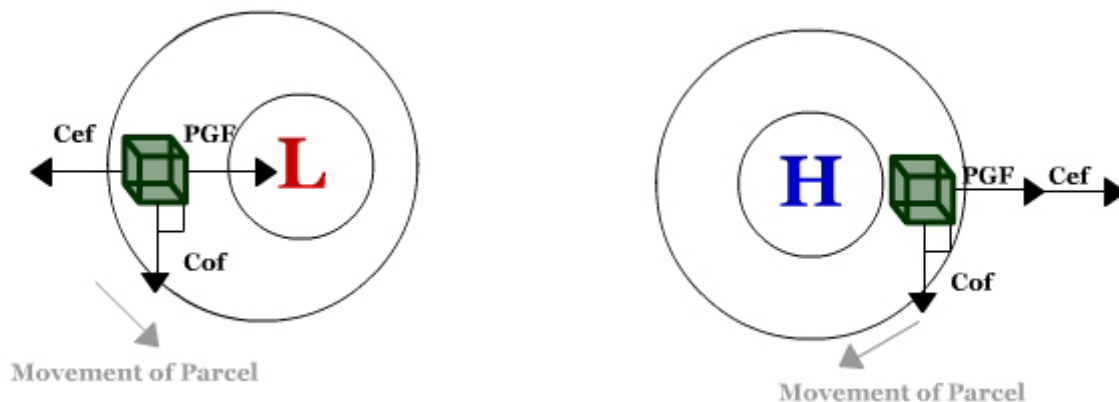

Figure 5 – Cef is always directed away from the center of rotation, and is non-existent with straight-line flow.

    b.   The strength of Cef depends on the velocity of the air parcels and the radius of curvature relevant to the strength of the pressure system.

        (1)   The greater the speed, or velocity, of a moving parcel of air, the greater the Cef for a constant curvature (a directly proportional relationship).

        (2)   Cef and radius of curvature are inversely related. As the radius of curvature increases, the velocity and Cef will decrease. A good example of this concept is a yo-yo. With the string to the yo-yo completely extended, the radius is long and the velocity that the yo-yo rotates about your finger is relatively slow. As the string gets wound up around your finger, the radius decreases and the yo-yo begins to rotate faster.

TRANSITION. In the lower portions of the troposphere, specifically below the gradient level, there is another force that acts upon the wind.

4.   Frictional Forces. Friction can be defined as the resistance encountered when one body is moved in contact with another. The

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surface of the Earth exerts a frictional drag on the air blowing just above it. This friction can act to change the wind's direction and slow it down keeping it from blowing as fast as the wind aloft.

   a.   The difference in terrain conditions directly affects how much friction is exerted. For example, a calm ocean surface is relatively smooth, so the wind blowing over it does not move up, down, and around any features. By contrast, hills and forests force the wind to slow down and/or change direction much more. Friction (Fr) always acts opposite to the direction of motion, or wind direction.

   b.   As we ascend in altitude, surface features have less of an affect on the wind. This level is considered the top of the boundary (or friction) layer. The height of the boundary layer can vary depending on the type of terrain, wind and vertical temperature profile. The time of day and season of the year also affect the height of the boundary layer. However, usually the boundary layer exists from the surface to about 1-2 km above it.
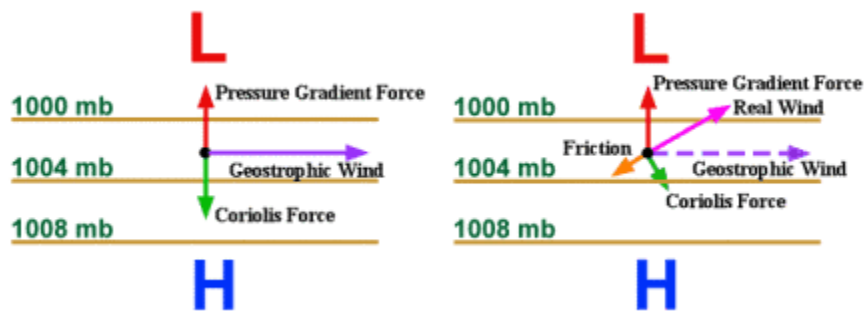

Figure 5 – The image on the left depicts a geostrophic wind, the image on the right illustrates how frictional forces act to slow the wind causing it to back and slightly cross the isobars.

   c.   In the friction layer, the turbulent friction that the Earth exerts on the air slows the wind down. This slowing causes the wind not to be geostrophic. As we look at figure 5, this slowing down reduces the Coriolis force, and the pressure gradient force becomes more dominant. As a result, the total wind deflects slightly towards lower pressure. The amount of deflection the surface wind has with respect to the geostrophic wind above depends on the roughness of the terrain.

OPPORTUNITY FOR QUESTIONS:

1.   Questions from the Class. At this time, are there any questions pertaining to the information that has just been presented to you?

2.   Questions to the Class.

   a.   QUESTION. Which force acts to initiate the wind?

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b. ANSWER. Pressure Gradient Force (PGF).

c. QUESTION. Which force is most dominate below the boundary level?

d. ANSWER. Friction (Fr).

e. QUESTION. Which force is responsible for deflecting particles to the right of path motion in the Northern hemisphere?

f. ANSWER. The Coriolis Force (Cof).

SUMMARY: During this period of instruction, the different types of atmospheric forces that affect wind movement were introduced. It was stated that the force responsible for iniating the wind is the PGF and directs wind flow from higher to lower pressure. Coriolis force acts to deflect particles to the right of path in the Norhern hemisphere due to the rotation of the Earth. Centrifugal force on a parcel of air acts outward and away from the center of rotation, while friction opposes wind motion below the gradient or boundary layer.

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